THE UNIVERSITY OF ALBERTA

HEMISPHERIC DIFFERENCES IN VISUAL AND TACTILE PERCEPTION OF BRAILLE-LIKE STIMULUS PATTERNS

by

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I wish to dedicate this thesis to Dr. Charles Beck, who got me started, to Dr. Eugene Lechelt, who got me going, and to my wife, Mary Ann Gillese-Schmidt, who got me finished.

ABSTRACT

This study was conducted to further define the distinction between the two hemispheres of the human brain, especially with regard to tactually perceived information. Tactile perception is, for the most part, dealt with by the right (spatial) hemisphere in righthanded persons. Hermelin and O'Connor (1971) and Rudel, Denckla, and Spalten (1974) have shown that the right hemisphere is superior in dealing with Braille patterns.

The present study used Braille-like patterns which were presented unilaterally to both visual and tactual modalities. The subject's task was to identify the location of three dots in a 2x3 six-dot pattern. Specifically, visual versus tactual presentation, dynamic versus static presentation of tactual stimuli, learning, and gender were examined in relation to hemispheric differences.

Across all three modes (visual, tactual-static, and tactual-dynamic), individual dots as well as complete patterns were reported significantly more accurately when presented to the left hemisphere. More specifically, both dots and patterns showed a significant left hemisphere superiority in the visual mode; in the tactual-dynamic mode, left hemispheric superiority was only found for recognition of dots; in the tactual-static mode, no significant hemispheric effect was found. However, for both patterns and

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This study was conducted to further define the distinction between the two hemispheres of the human brain, especially with regard to tactually perceived information. Tactile perception is, for the most part, under the control of the right (spatial) hemisphere in normal right handed persons. Hermelin and O'Connor (1971) and Rudel, Denckla, and Spalten (1974) have shown that the right hemisphere is superior in dealing with braille patterns.

The present study used braille-like patterns which were presented unilaterally to both visual and tactual modalities. The subject's task was to identify the location of three dots in a two-by-three matrix. Specifically, visual versus tactual presentations, within versus across modality presentation, of tactual stimuli, learning, and gender were examined in relation to hemispheric differences.

Across all three modes (visual, tactual-static, and tactual-dynamic), individual dots (as well as complete patterns) were reported significantly more accurately when presented to the left hemisphere. More specifically, both dots and patterns showed a significant left hemispheric superiority in the visual mode; in the tactual-dynamic mode, left hemispheric superiority was only found for recognition of dots; in the tactual-static mode, no significant hemispheric effect was found. However, for both patterns and

dots there was a significant hemisphere x learning interaction in the tactual-dynamic mode. Theoretical implications of differential hemispheric specialization are discussed in terms of differential processing.

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Recent research has suggested that the two hemispheres of the average normal adult human brain, as well as having some biological distinctions (Geschwind and Levitsky, 1968; Le May and Culebras, 1972), contribute differentially to the perception and interpretation of meaningful stimuli (Gazzaniga, 1972; Kimura, 1973; Semmes, 1968). Anatomically, the temporal cortical areas involved in speech (those of Broca and Wernicke) are larger in the left hemisphere of most human brains, with a concomitant enlargement of the right parietal areas (Geschwind, 1974). In behavioral terms, it seems that the left hemisphere in most righthanded (dextral) people is more proficient than the right in handling verbal material or material to which verbal labels may be easily applied (Bryden, 1970; Hilliard, 1973; Kimura, 1966). The right hemisphere, while not able to handle verbal material beyond a very rudimentary level (Gazzaniga, 1970; Gazzaniga and Hillyard, 1971), is, however, more specialized for "non-verbal" abilities (Kimura, 1969; McKeever and Hulling, 1970).

This dichotomy has been shown to hold when the stimuli are either visual (Fontenot and Benton, 1972; Geffen, Bradshaw, and Wallace, 1971; Levy, Trevarthen, and Sperry, 1972) or auditory (Kimura, 1967; King and Kimura, 1972; Schulhoff and Goodglass, 1969). In vision, the abilities of the right hemisphere include the perception of unfamiliar complex stimuli (Bradshaw, Geffen, and Nettelton, 1972;

Kimura, 1963; Milner, 1968; Rubino, 1970), depth (Durnford and Kimura, 1971), spatial orientation (Benton, Levin, and Van Allen, 1974; Bowen, Hoehn, and Yahr, 1972; Umilta, et al., 1974), and spatial localization (Kimura, 1969). The right hemisphere's auditory capabilities include the perception of vocal non-verbal stimuli (Blumstein and Cooper, 1974; Carmon and Nachshon, 1973; King and Kimura, 1972), unfamiliar melodies (Bartholomeus, 1974; Bever and Chiarello, 1974; Kimura, 1964), and "environmental" sounds (Curry, 1967; Knox and Kimura, 1970).

There is also evidence that lateralization of function occurs in the tactile sense. This evidence is based upon studies using normal subjects, as well as those using brain damaged and split-brain subjects. Examining the literature, one is impressed by the apparent "dominance" of the *right* hemisphere within the tactual mode. This impression is fostered by the preeminence of the right hemisphere in most tactual tasks. The right hemisphere has been shown to outperform the left in the tactile perception of complex shapes (de Renzi, 1968; Milner, 1971), spatial orientation (Benton, Levin and Varney, 1973; Nebes, 1973), spatial localization (Faglioni, Scotti and Spinnler, 1971), degree of curvature (Nebes, 1971), and temporal patterns (Lechelt and Tanne, 1975).

Historically, the first real investigation of the tactile sense was conducted by Weber during the 1830's

(cited by Weinstein, 1968). Weber's studies were directed toward the differences in sensitivity among the various body parts. His concern was not with lateralization (about which there was little knowledge until Broca's discoveries, thirty years later), but he did lay the foundation for further investigation into the various aspects of tactile sensitivity.

Weinstein (1968), in the first extensive quantitative study, demonstrated that cutaneous sensitivity in terms of two-point threshold, localization, and intensive stimulation is lateralized, though his results are not unequivocal (probably due to the simplicity of his stimuli). With more complex stimulation and different techniques, other investigators have produced more positive results.

Boll (1974) has shown that when patients with lateralized brain lesions were compared with respect to contralateral and ipsilateral tactile perceptual difficulty on three non-verbal tasks, patients with right hemisphere brain damage were more impaired on both contralateral and ipsilateral hands than were those with comparable damage to the left hemisphere. Carmon and Benton (1969) and Fontenot and Benton (1971) have produced similar results. The right hemisphere, isolated by means of callosum section, has also been shown to be better than the left at such tasks as judging the size cf a complete circle from a small arc (Nebes, 1971) and in the unification of figures from their

"exploded" parts (Nebes, 1972).

Benton, Levin, and Varney (1973) have conducted a study wherein linear arrays of three small circular stimulators were presented to subjects' palms and the subjects were asked to respond with judgments of the orientation of the array. They found that judgments were more accurate when the stimuli were presented to the left hand, i.e. to the right hemisphere. Varney and Benton (1975) confirmed these results and also found that handedness is a good determinant of the side of lateralization when familial handedness is taken into account.

Directly related to the present research was the finding of lateralization in small-number dot pattern recognition (Schmidt, 1974). Right-handed subjects were presented with different pairs of three-dot stimulus patterns from a six-dot array. The apparatus used was similar to that used in the present study and included a mechanism which produced a passive scan of one or two stimulus patterns by the subject's fingertips. Two patterns were presented simultaneously, one to each index finger. This was followed by a third (probe) pattern, which was presented to one finger or the other. The probe was either one of the pair or a "new" pattern. Subjects were asked if they recognized the third pattern as being one of the pair. Paired patterns were considered to be in competition with each other since they were presented simultaneously and

required equal finger pressure for either to be felt. Since each stimulus pattern would be expected to enter into the contralateral hemisphere directly and only minimally (via the corpus callosum) to the ipsilateral hemisphere, it was predicted that in the paired condition the patterns presented to the left hand would be more accurately perceived than those presented to the right hand. Both hemispheres would have freer access to the probe, as it was presented without competition.

Three types of trials were employed: (1) the probe was the same as the paired stimulus pattern on the same side; (2) the probe was the same as the paired pattern on the other side, and (3) the probe was different from both paired patterns ("new"). Though there was a definite tendency for the paired stimulus pattern on the left side to be recognized more often in the first two trial types, reliable differences ($t=1.913$; $d.f.=25$, $p<.05$) occurred only within trials where the probe was different from either paired pattern. Also, since accuracy on the first trial type was much higher (69.3%) than for the second type (48.1%), the difficulty in recognition seemed to result from the subjects' attempts to compare the probe with the paired stimulus pattern from the opposite side. Therefore, when a "new" pattern was given as a probe, it tested the paired pattern from the other side. It was concluded that the tactile perception of small number dot-patterns was essen-

tially a right hemisphere function when the patterns were presented in a simultaneous, competitive situation and tested on recognition.

Hermelin and O'Connor (1971) have investigated the abilities of blind persons to read Braille dot patterns. They speculated that, although the patterns were spatial arrangements, to their subjects the patterns should represent well-learned verbal elements. They questioned whether performance would be better with the right hand/left hemisphere due to the verbal aspect of the stimuli, or with the left hand/right hemisphere due to the spatial aspect. They found: (1) blind children (aged 8 to 10 years) who were asked to read Braille sentences performed better, in terms of speed and accuracy, with their left hands, especially when the unpracticed middle fingers were used, and (2) although blind adults were more accurate in reading vertically arrayed letter symbols with their left hand, they did not differ in speed of reading. Hermelin and O'Connor suggest that the differences in performance between hands is at least partially due to hemispheric asymmetry and, further, that the stimuli presented to the right hemisphere, via the left hand, are more accurately perceived due to the need for preprocessing of the spatial array before verbal significance may be attached to it.

Rudel, Denckla, and Spalten (1974) have shown that, when selected Braille characters were presented to sighted

children having no previous experience, results similar to those obtained by Hermelin and O'Connor occurred. This strengthens the rather tentative conclusions of the latter authors with regard to laterality. If naive sighted, as well as experienced blind persons, are more able to handle Braille characters when perceiving them with their left hands, then one is not able to criticize such findings on the basis of some learned lateral preference.

Milner and Taylor (1972) have found supporting evidence for the conclusicns expressed above, using split-brain subjects. They were able to show that the isolated right hemisphere, as well as being better than the left hemisphere at perceiving unfamiliar irregular wire figures, was superior at perceiving familiar nameable objects. Witelson (1974) has confirmed the results of Milner and Taylor using dichotomous stimulation to present verbal and non-verbal stimuli to normal children (aged 6 to 14 years).

The evidence presented by Hermelin and O'Connor, Rudel, Denckla, and Spalten, Milner, and Witelson suggests that, in the tactile sense, a mode of processing prevails which is different from that in the visual or auditory senses. Essentially, it seems that the tactile system is organized specifically for the perception of spatial information. It is only with considerable processing of that information that verbal aspects, if any, may be derived. From this, it is only a short step to the conclusion that the right

hemisphere is better organized to process tactile information than the left, at least at the basic (spatial) level.

The present study is a further investigation into the laterality differences in the tactile perception of spatial arrays. One of the problems considered is that if such perception is more accurately accomplished by the right hemisphere, what are the effects on this lateralization when the stimulus patterns are presented in a "dynamic" fashion, as opposed to a "static" presentation? In other words, how does perception of the stimulus when the pattern is scanned by the subject compare with that when the pattern is not scanned?

Apkarian-Stielau and Loomis (1975), following the work of Loomis (1974), suggest that scanning facilitates tactile perception. In their experiment, block letters were presented via a 400-point vibrotactile array to the subject's back. When the stimulus was "scanned", as if viewed through a horizontally moving vertical slit, performance level was increased markedly. Admittedly, the back is not as fine a perceptual device as the fingertip, but it seems that the findings of Apkarian-Stielau and Loomis are somewhat generalizable to all tactually receptive surfaces. Furthermore, Apkarian-Stielau and Loomis demonstrated that tactile perception on the back resembles visual perception

when the visual stimuli are blurred by approximately thirty diopters. It may be suggested, therefore, that visual perception of dot patterns would be approximated by (though likely better than) tactile perception of the same patterns. To facilitate comparison, visual presentation should be non-foveal and of short duration (twenty milliseconds), while tactile presentation should be to the fingertips and of longer duration (one second).

The present study, therefore, also incorporated an analogous task in the visual mode in order that performance on such a task might be used to evaluate that obtained with the two types of tactual presentation. In this manner, one might determine something of the similarities and distinctions in functional lateralization between the tactual and visual senses. Small dot patterns, similar to those used in Braille, were presented unilaterally for brief periods of time. Numerical identification of dot positions was used as a response mode. This was not expected to have a discernable effect on the outcome of the experiment, since it was thought that identification of individual dots would be most easily done after the complete pattern had been perceived.

It was predicted that right-handed subjects would perform better at this task when the stimuli are presented to their right hemisphere via the left hand or left visual field. The ease of perception of the stimuli was also predicted to inversely affect the difference in performance

between the two sides. Thus, in the visual mode, where the stimuli should be most easily perceived, the difference in performance between the left and right sides should be the least. In the two tactual modes of presentation, dynamic and static, one would expect the latter to produce greater perceptual difficulty and, thus, a greater distinction between the two sides.

Also of interest is the effect of learning on the relative performance of the two sides. Unless asymptotic performance is reached early by the subject, he/she would be expected to increase his/her performance as he/she gains more experience with the stimulus patterns. The question then is whether or not the two sides will learn at the same rate. It might be conjectured that the right hemisphere will increase its performance as it attains experience with the overall array, while the left hemisphere should maintain a more constant level of performance as it attempts to deal with each dot in the pattern individually. This would be consistent with the different cognitive processing strategies of the two hemispheres suggested by such authors as Semmes (1968).

The effect of learning may also interact with that of presentation mode. Thus, it may be predicted that the easier the task the less learning is likely to occur, due to the higher performance on the early trials. However, it may occur that the difficulty encountered by the subjects on the

tactual task may prevent significant learning during the limited number of trials.

One other predictable effect is that of gender. Kimura (1969) indicates that, in some cases, males tend to perform better in visual spatial localization tasks than do females. She also demonstrates that males show the laterality effect (right hemisphere better than left on spatial tasks) more readily than females. McGlone and Kertesz (1973), in the visual mode, and Knox and Kimura (1970) and Lake and Bryden (1976), in the auditory mode, have found support for Kimura's conclusions. Generalizing to the tactual mode, and taking note of Witelson's (1976) results, one may predict that gender will be a determining factor in overall performance, with males being better, as well as interacting with the side of presentation, so that males will show a greater favoring of the stimuli presented on the left side than will females. The effect of gender may also interact with that of presentation mode such that, as difficulty of the task increases, so also will the male/female discrepancy.

An attempt was made to incorporate testable aspects of each of the issues mentioned in the preceding paragraphs into the present work. To accommodate this intention, certain hypotheses were advanced, based upon the findings and conclusions of previous investigators. Briefly stated, these hypotheses are:

1) that numerical identification of dots, as a response mode, would, in itself, have minimal effect on the processing of the stimulus patterns;

2) that the right hemisphere (left hand and visual field) would perform better than the left hemisphere (right hand and visual field);

3) that performance on the visual task would be comparable to that on the tactual tasks, though possibly slightly better;

4) that scanning in the tactual task would facilitate performance;

5) that the more difficult task would provide the larger difference between the hemispheres;

6) that learning would occur differentially for the two hemispheres, such that the right hemisphere would show a greater increase in performance than the left; and,

7) that males would perform better than females, or, at least show a greater right hemisphere superiority than females.

For the purposes of facilitating discrimination of the relative abilities of the two hemispheres, the performance of each was measured in terms of both the number of individual dots identified and the number of complete dot

patterns identified. Essentially, it was expected that the measure based on complete patterns (McKeever and Huling 1970) would show a greater right hemisphere superiority than that based on individual dots (Bryden, 1976), though the latter has been shown to be somewhat useful (Kimura, 1969).

Another consideration was that the two hemispheres might produce different numbers of "shift errors". Shift errors are those in which the relative distances among the dots are correctly determined, but the complete pattern is shifted by one position in either axis. It was thought that the right hemisphere, as well as being more accurate with regard to identifying complete patterns, would also tend to make a greater number of shift errors.

Method

Subjects

Subjects from a pool of volunteers from undergraduate university courses were initially screened using the handedness inventory designed by Varney and Benton (1975, see Appendix I). Volunteers were eliminated from the pool if they indicated left or mixed lateral preference on three or more activities in the inventory, or if either one or both parents or two or more siblings were lefthanded. Those remaining in the pool were then considered to be strongly righthanded and, from these, thirty subjects were randomly selected, fifteen males and fifteen females.

All subjects participating in the visual part of the experiment had normal or corrected vision. No subjects in the tactual parts of the experiment had any impediment to the use of their middle fingers (i.e., no scar tissue or long fingernails).

Apparatus

Tactual. Tactile patterns were presented by a motor-driven, horizontally moving platform and a vertically moving stimulus mount underneath the platform (see Plates 1 and 2). The platform was constructed so that, when subjects placed both hands on it, the middle finger of each hand rested in a

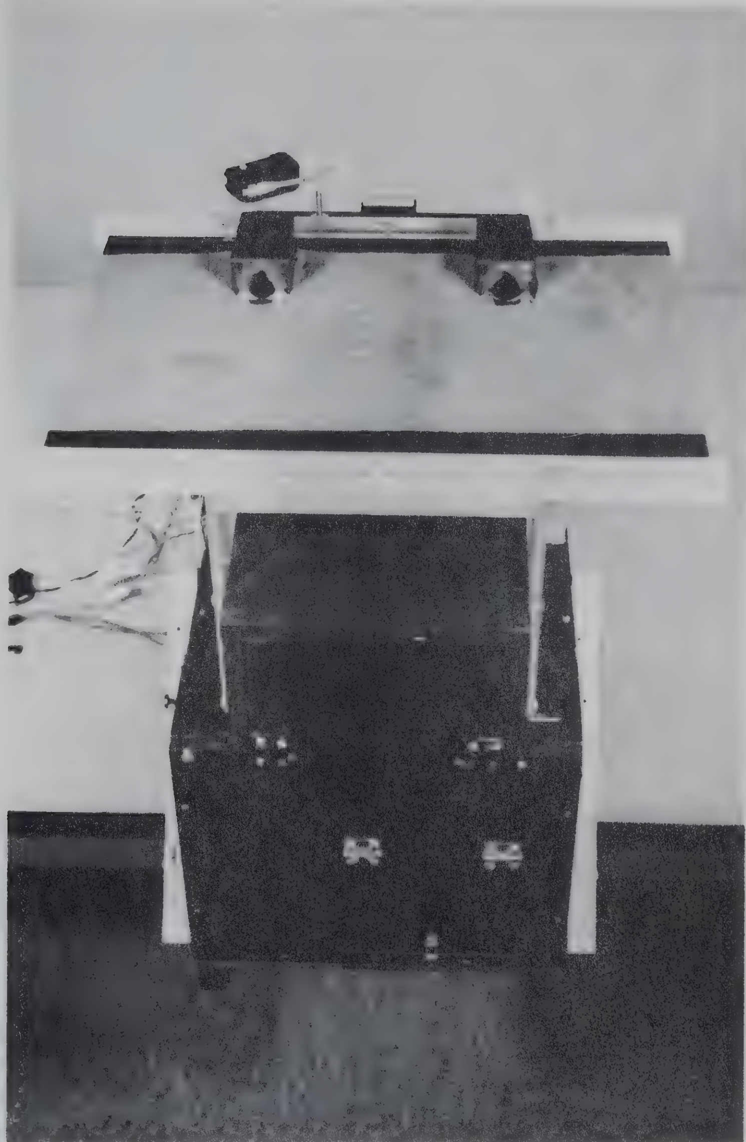


Plate 1. Tactual-presentation apparatus. Shown is the platform upon which the subject placed both hands with the middle fingers in the guides. Note that the removeable barrier (with handle at top, center) and microswitch were not visible to the subject because of an interposed opaque screen which prevented the subject from seeing the stimulus patterns and also supported the warning light.

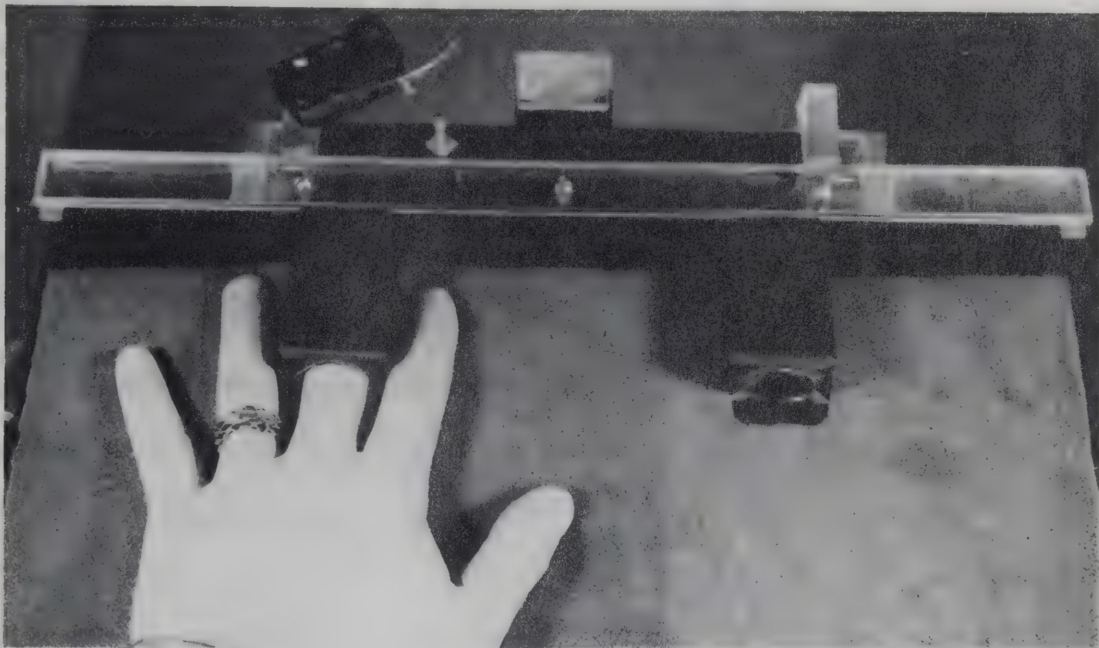
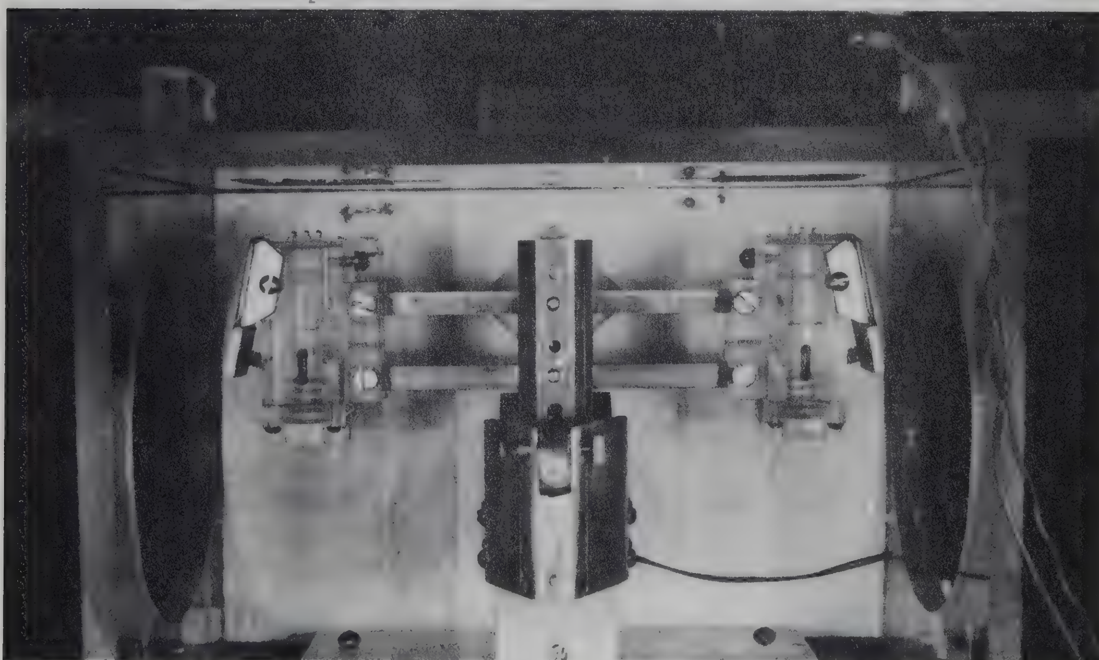


Plate 2. Platform with one hand properly positioned. The platform may either remain stationary (as in the photograph) or be made to move from side to side. Again, the removeable barrier and microswitch would not normally be visible from this viewpoint.



.Plate 3. Stimulus mount from the experimenter's viewpoint. The mount is in the lowered position to allow the stimulus patterns to be changed. Note the double fulcrum, which produced the need for equal pressure on both sides, while keeping the stimuli vertically oriented.

covered guide over a small hole, through which the tip of the finger protruded (see Plate 3). The finger guide restricted voluntary movement of the fingertips. The stimulus mount could hold a stimulus pattern under either finger in such a way that, when the fingertip protruded through the platform, it touched the stimulus pattern. When a stimulus pattern was under one finger, a flat surface was under the other. The stimulus mounts were interconnected by a balanced-fulcrum mechanism. Thus, equal pressure on both fingertips was required to ensure perception of the stimuli, since the application of pressure to only one side would cause that side to withdraw from the fingertip, making perception difficult. The stimulus mount was spring loaded so that, at the end of each stimulus presentation, a release mechanism was electronically activated, removing the stimuli from direct contact with the fingertips. Before each stimulus presentation, a panel was interposed between the platform and the stimulus mount. Removal of this panel started the timing sequence for each trial. The apparatus also contained a small warning light to alert the subject to the advent of a trial. The trial duration was controlled by a calibrated Hunter timer which was activated by a microswitch connected to the barrier panel.

During stimulus presentation, the platform upon which the hands rested either moved from side to side, so that each fingertip passed from one side of its stimulus to the

other, or it remained stationary, so that each fingertip was directly over its stimulus pattern.

The stimuli were .0625 inch (1.59mm) diameter plexiglass pins with rounded tips. Six of these pins were arranged in a two-by-three grid under each finger, with the long axis of the array perpendicular to the finger. Each pin sat on a spring-supported piston so that slight finger pressure would push it down. The pins were .15 inch (3.81mm) from center to center. The total array covered an overall area of .3625 X .2125 inches (9.21 X 5.4mm). Such constraints were placed on the stimulus array so that it would fit within, as well as conform to the curvature of adult middle fingertips.

The stimulus patterns were created by placing thin plexiglass plates over the pins which allowed only selected pins through to make contact with the fingertip (see Plate 4). The present study used twenty patterns, each consisting of three pins. These twenty patterns were all the possible selections of three pins from six, and included:

123	124	125	126	134	135	136	145	146	156
•••	••	••	••	• •	• •	• •	•	•	•
	•	•	•	•	•	•	••	• •	••
234	235	236	245	246	256	345	346	356	456
••	••	••	•	•	•	•	•	•	
•	•	•	••	• •	••	••	• •	••	•••

Note that every stimulus pattern has its mirror image in another pattern, except for 123, 135, 246, and 456 which are

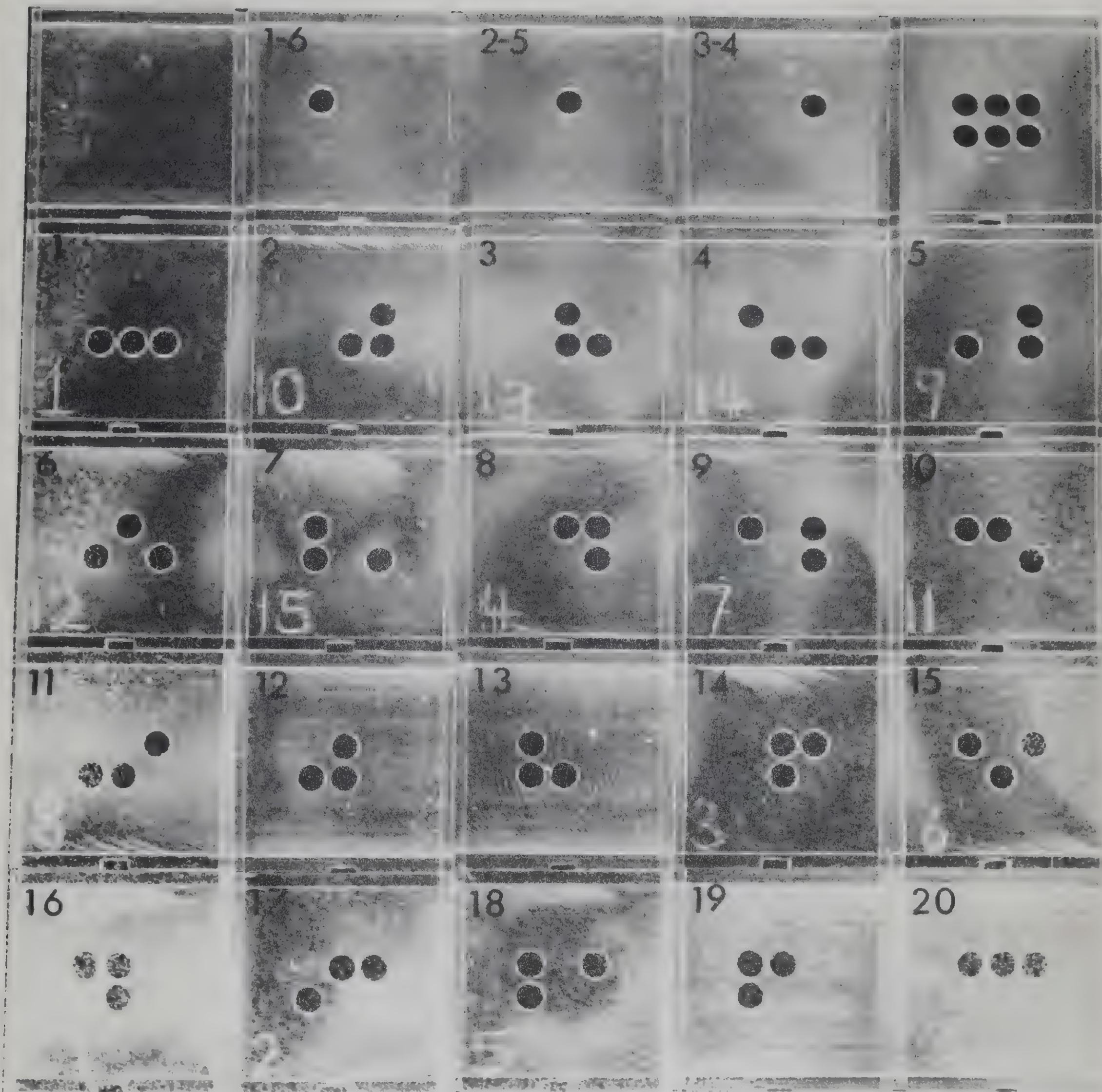


Plate 4. Plates used to produce different stimulus patterns, numbered from 1 to 20, as viewed by the experimenter. Note that the subject would perceive the stimuli from the opposite direction. Also shown are the three single-dot plates, as well as the the blank plate and one producing the full six-dot array.

horizontally symmetrical, and therefore are mirror images of themselves.

Visual. For the visual part of the experiment, a Gerbrands three-channel tachistoscope (Model T1C3 C) was used to present the stimuli. The stimuli were black dots ("Letraset", LD-14-B) on white cards (photograph-mounting board), arranged in the same patterns as the tactile stimuli. Each dot was .125 inch (3.18mm) in diameter and subtended a visual angle of .34 degrees. The dots were spaced .3 inch (7.62mm) from center to center. The inside boundary of the complete array was displaced 1.64 degrees left or right from a central fixation point and subtended a horizontal visual angle of 1.97 degrees. The vertical visual angle subtended by the total array was 1.16 degrees. The fixation point was marked with a small "+".

The luminance levels for the three channels of the tachistoscope were measured using a Photo Research "Spectra Spotmeter", Model UBD-1°. Measurements were taken both before any subjects had participated in the visual task and after all subjects had been run. There was close agreement between the pre- and post-experiment measurements.

The three channels were designated "blank", "fixation", and "stimulus". Luminance levels for the three channels were 7.1, 5.5, and 4.9 candellas/meter^2, respectively. As will be noted in the procedure section, the three channels were

activated for different periods of time, during the experiment, and this variation was reflected in the differences in luminance levels. Note, also, that the "stimulus" channel was measured while the full arrays were inserted, and the luminance level may have been slightly higher during presentation of each of the stimulus patterns.

Procedure

The study was divided into three separate parts: tactual-static (TS), tactual-dynamic (TD), and visual (V). The stimulus patterns for each part were the same. Subjects were tested individually.

Tactual-Static. Each subject was instructed according to the form in Appendix IIA. He or she was told that tactual discrimination was being studied (no mention was made of the laterality aspect). Then an illustration of the six-dot array, with each of the dots numbered, was shown and the subject was asked to remember the number for each position. Then the subject placed both hands on the apparatus with the middle fingers properly positioned in the guides directly over the stimulus arrays. The full six-dot arrays were presented on both sides (to both middle fingers) and the subject was asked if all dots could be felt. When an affirmative answer was received, the arrays were removed and the practice trials were begun. All trials were preceded by a one-second illumination of the warning light. At the

offset of the warning light, the interposed slide was removed from between the fingertips and the stimuli. Each practice trial consisted of a one-second presentation of a single dot to one side or the other. The position of the dot in the array and the side of presentation varied according to a predetermined random order. Twenty-four practice trials were given, including two presentations of each dot position on each side. After each dot was presented, the subject was asked to give its position by saying the appropriate number. Immediate feedback was given for each trial by telling the subject whether or not the response was correct and, if not, what was the correct response.

After the practice trials had been completed the subject was informed that all subsequent trials would be the same except that each would have a three-dot pattern rather than a single dot. The subject was asked to respond by giving the numbers for each of the three dot positions in each stimulus. No feedback was given on these trials. Each subject was presented with forty trials, which included two presentations of each stimulus, once per side.

Five random orders of stimulus presentation had been determined (see Appendix III) and each of these was presented to one male and one female in each group. For the purposes of analysis, the forty trials in each order were divided into five groups of eight trials (four on each side) such that, within each group, the stimulus presentation was

on the same side no more than twice in succession. No distinction was made between groups of trials during presentation.

Tactual-Dynamic. The procedure for this part of the experiment was the same as that for the tactual-static condition except that, during the non-practice trials, the apparatus was set to produce a passive scan of the stimuli. This was accomplished by side-to-side movement of the motorized platform which supported the hands. The platform completed one cycle (during which the center of the finger moved from one side of the stimulus pattern to the other, and back again) during the one-second trial. The motor was activated just prior to the removal of the interposed slide and stopped at the end of the trial.

Visual. The visual part of the experiment is very similar to the other two parts. The instructions (see Appendix IIB) are the same except for the modifications necessary to apply them to this task.

The room containing the visual apparatus was darkened except for a small shielded lamp used by the experimenter to read the instructions and record the subject's responses. The subject was thus able to adapt to limited light conditions for a short period before viewing the stimuli.

The blank channel remained on throughout the experiment. Whenever either the fixation or stimulus channels were

on, they were superimposed on the blank field.

Each trial consisted of a one-second presentation of the fixation "+". At offset of the fixation channel the stimulus channel was activated. During the first half of the practice trials, the stimuli were presented for thirty milliseconds to acquaint the subject with the task. On all other trials, the stimuli were presented for twenty milliseconds.

Results

Subjects' performance was measured in terms of both the number of stimulus dots correctly identified and the number of complete three-dot patterns correctly identified.

Each value represents the average number of dots or patterns correctly identified by the five subjects in each gender x mode grouping and within each grouping of four trials for each side of presentation.

Practice Trials

A preliminary analysis of subjects' performance on the practice trials was made to determine if there were any predisposing differences between genders, modes of presentation, or sides of presentation when only one dot was presented in each trial. Particular interest was paid to the differences between the two tactile presentation modes, as these had exactly the same practice sessions. No significant differences were found within the practice trials.

Comprehensive Analyses

Table 2 contains the means for all main effects, for both patterns and dots. As in Table 1 (from which these means are derived), the maximum values for each are four and twelve, respectively. The data for both patterns and dots were first analyzed as a 3x2x5x2 (mode x gender x trial

Table 1

A. Mean Number of Complete Patterns Correctly Identified on Four-Trial Blocks for Each Side of Presentation by Five Subjects per Gender Within Each Mode.

		Side of Presentation									
		Left Trial Blocks					Right Trial Blocks				
Mode	Gender	1	2	3	4	5	1	2	3	4	5
TS	Male	1.4	1.0	1.4	2.8	3.2	2.0	2.6	1.8	1.4	2.8
	Female	1.8	1.2	1.8	3.4	2.6	1.8	1.6	2.4	2.8	2.6
TD	Male	0.6	1.0	1.4	1.0	1.4	0.8	1.0	1.2	1.8	1.4
	Female	0.4	1.6	1.4	1.6	1.2	1.8	2.0	0.8	1.6	2.0
V	Male	1.8	1.6	1.8	1.4	2.0	2.0	2.0	2.4	2.8	2.4
	Female	1.0	1.2	1.8	1.6	2.2	1.4	2.2	2.2	2.8	2.8

B. Mean Number of Individual Dots Correctly Identified on Four-Trial Blocks for Each Side of Presentation by Five Subjects per Gender Within Each Mode.

		Side of Presentation									
		Left Trial Blocks					Right Trial Blocks				
Mode	Gender	1	2	3	4	5	1	2	3	4	5
TS	Male	8.0	8.0	8.0	10.2	11.0	9.6	10.2	8.8	8.6	10.2
	Female	8.4	7.6	9.2	11.0	10.2	8.8	9.4	9.6	10.2	9.6
TD	Male	7.0	7.2	8.2	7.4	7.8	6.2	7.2	8.2	9.4	8.2
	Female	6.4	7.8	8.4	8.2	8.2	9.4	9.2	8.0	9.0	9.0
V	Male	9.2	8.6	8.2	8.6	8.6	9.6	9.2	9.6	10.6	9.8
	Female	7.0	7.8	9.0	8.0	9.4	7.8	9.2	9.0	10.4	10.0

Note: The maximum value for any cell in Table 1A is 4.0, and in Table 1B is 12.0.

Table 2

Means for Main Effects.

	Gender		
	Male	Female	
P[1]:	1.74	1.85	
D[2]:	8.71	8.84	

	Mode		
	TS	TD	V
P:	2.12	1.30	1.97
D:	9.33	8.02	8.98

	Learning (Trial Blocks)				
	1	2	3	4	5
P:	1.40	1.58	1.70	2.08	2.22
D:	8.12	8.45	8.68	9.30	9.33

	Side	
	Left	Right
P:	1.62	1.97
D:	8.42	9.13

[1]Patterns: maximum=4.
[2]Dots: maximum=12.

blocks [learning] x side of presentation) factorial design with subjects nested within mode and gender.

A summary of the overall analysis of variance for complete patterns is presented in Table 3. The effect of gender was found to be non-significant. The effect of mode was significant ($F=4.36$; d.f.=2,24; $p<.025$). The increase in performance over trial blocks was significant ($F=5.57$; d.f.=8,96; $p<.001$). Also, performance was significantly better when patterns were presented on the right side than when they were presented on the left side ($F=10.91$; d.f.=1,24; $p<.005$). Lastly, a significant interaction was found among the mode x learning x side of presentation effects ($F=2.50$; d.f.=8,96; $p<.025$). The Tukey Test (Kirk, 1968, p. 268) was used to test for significance between mean pairs within mode. Although TS and TD differed significantly ($q=3.92$; d.f.=3,24; $p<.05$), TS and V, as well as TD and V, did not differ reliably. When the mean for TD was compared with those of both TS and V, combined, using Scheffe's ratio (Kirk, 1968, p. 269) the difference was significant ($F=8.46$; d.f.=2,24; $p<.01$).

A summary of the overall analysis of variance for dots is given in Table 4. The results of this analysis essentially mirror those for complete patterns, with statistical significance occurring for mode ($F=4.85$; d.f.=2,24; $p<.025$), learning ($F=5.24$; d.f.=4,96; $p<.001$), and side of presentation ($F=33.68$; d.f.=1,24; $p<.001$). Note,

Table 3

Overall Analysis of Variance for Patterns.

Source	SS	df	MS	F
Gender	0.96	1	0.96	0.22
Mode	38.13	2	19.06	4.36*
G x M	1.89	2	0.94	0.22
Subjects(G x M)	104.92	24	4.37	
Learning [trial blocks]	28.25	4	7.06	5.57***
G x L	2.15	4	0.54	0.42
M x L	8.57	8	1.07	0.85
G x M x L	10.55	8	1.32	1.04
Subjects(G x M) x L	121.67	96	1.27	
Side	9.36	1	9.36	10.91**
G x S	0.16	1	0.16	0.19
M x S	3.85	2	1.92	2.24
G x M x S	0.33	2	0.16	0.19
Subjects(G x M) x S	20.60	24	0.86	
L x S	2.15	4	0.54	0.67
G x L x S	1.02	4	0.25	0.32
M x L x S	16.19	8	2.02	2.50*
G x M x L x S	6.24	8	0.78	0.97
Subjects(G x M) x L x S	77.58	96	0.81	

*p<.025
**p<.005
***p<.001

Table 4

Overall Analysis of Variance for Dots.

Source	SS	df	MS	F
Gender	1.20	1	1.20	0.13
Mode	92.01	2	46.01	4.85*
G x M	15.69	2	7.84	0.83
Subjects(G x M)	227.44	24	9.48	
Learning [trial blocks]	68.09	4	17.02	5.24**
G x L	4.25	4	1.06	0.33
M x L	10.59	8	1.32	0.41
G x M x L	37.31	8	4.66	1.44
Subjects(G x M) x L	311.95	96	3.25	
Side	38.16	1	38.16	33.68**
G x S	0.56	1	0.56	0.50
M x S	6.85	2	3.42	3.02
G x M x S	3.73	2	1.86	1.64
Subjects(G x M) x S	27.20	24	1.13	
L x S	9.49	4	2.37	0.89
G x L x S	6.55	4	1.64	0.61
M x L x S	39.75	8	4.97	1.86
G x M x L x S	19.01	8	2.38	0.89
Subjects(G x M) x L x S	256.16	96	2.67	

*p<.025
**p<.001

however, that the *F* is considerably larger for the side of presentation effect when dots are considered than when complete patterns are considered, and that the mode x learning x side of presentation interaction is not quite significant in the dots analysis ($F=3.02$; d.f.=2,24; $p=.068$). The Tukey Test was used to examine the pairwise comparisons within mode. The difference between TS and TD was significant ($q=4.26$; d.f.=3,24; $p<.05$), though between TS and V and TD and V the differences were not significant. Scheffe's ratio was used to compare the mean of TD with those of TS and V, combined, and the difference was found to be significant ($F=9.06$, d.f.=2,24; $p<.01$).

Tactual Modes Only

The analyses for patterns and dots were repeated after elimination of the visual mode data. With respect to patterns, considering both tactual modes, significance occurred for mode ($F=11.60$; d.f.=1.16; $p<.005$), learning ($F=3.99$; d.f.=4,64; $p<.01$), and the mode x learning x side interaction ($F=2.77$; d.f.=4,64; $p<.05$). With respect to dots, significance occurred for mode ($F=12.70$; d.f.=1,16; $p<.005$), learning ($F=3.92$; d.f.=4,64; $p<.01$), and side of presentation ($F=10.12$; d.f.=1,16; $p<.01$).

Within Individual Modes

In Table 5 the means from Table 2 have been broken down

Table 5

Means Within Modes.

Tactual-Static

Gender

	Male	Female
P[1]:	2.04	2.20
D[2]:	9.26	9.40

Learning (Trial Blocks)

	1	2	3	4	5
P:	1.75	1.60	1.85	2.60	2.80
D:	8.70	8.80	8.90	10.00	10.25

Side

	Left	Right
P:	2.06	2.18
D:	9.16	9.50

Tactual-Dynamic

Gender

	Male	Female
P:	1.16	1.44
D:	7.68	8.36

Learning (Trial Blocks)

	1	2	3	4	5
P:	0.90	1.40	1.20	1.50	1.50
D:	7.25	7.85	8.20	8.50	8.30

Side

	Left	Right
P:	1.16	1.44
D:	7.66	8.38

Visual

Gender

	Male	Female
P:	2.02	1.92
D:	9.20	8.76

Learning (Trial Blocks)

	1	2	3	4	5
P:	1.55	1.75	2.05	2.15	2.35
D:	8.40	8.70	8.95	9.40	9.45

Side

	Left	Right
P:	1.64	2.30
D:	8.44	9.52

[1]Patterns: maximum=4.
[2]Dots: maximum=12.

into means for each of the three modes. The means for learning, with respect to dots, have been further divided into those for each side of presentation and are presented in Figure 1 to illustrate the three-way interaction.

Tactual-Static. Within the tactual-static mode (see Table 6) the learning effect was significant for both patterns ($F=5.67$; $d.f.=4,32$; $p<.005$) and dots ($F=3.86$; $d.f.=4,32$; $p<.025$). No other main effect was significant in either analysis. However, a significant learning x side interaction did occur in both cases (patterns: $F=3.52$; $d.f.=4,32$; $p<.025$; dots: $F=3.35$; $d.f.=4,32$; $p<.025$). This interaction (see Figure 1, top) was further explored with respect to dots via an analysis of variance for differences in trends (Kirk, 1968, pp. 270-275). It was found that the difference in linear trend was significant ($F=8.71$; $d.f.=1,32$; $p<.01$) as was the difference in cubic trend ($F=4.42$; $d.f.=1,32$; $p<.05$) and that the two, combined, accounted for more than 98 percent of the difference.

Tactual-Dynamic. Within the tactual-dynamic mode (see Table 7) the analyses for patterns and dots were not consistent with each other. In the case of patterns, no significant effect was found, although the effect of side of presentation did approach significance ($F=3.50$; $d.f.=1,8$; $p=.098$). With the analysis based on dots, however, the effect of side of presentation was significant ($F=19.79$; $d.f.=1,8$; $p<.005$). There also occurred a significant

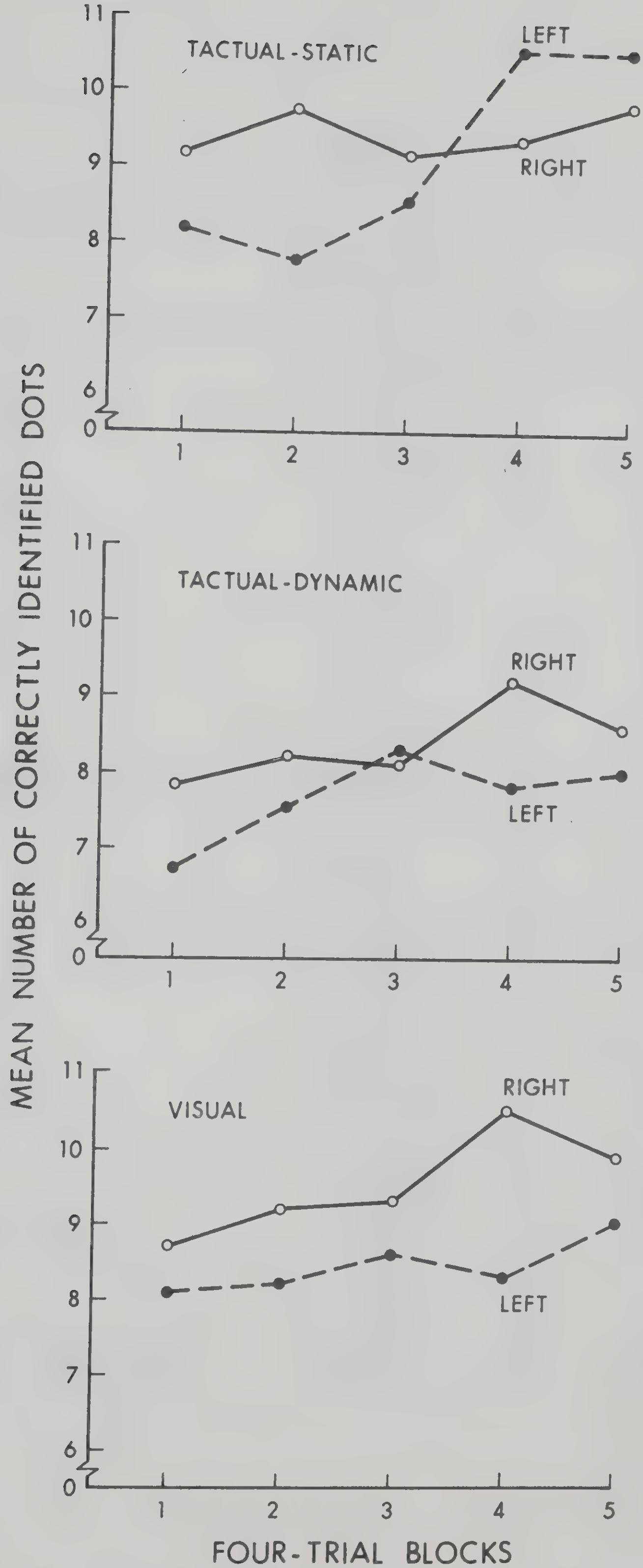


Figure 1. Performance over trial blocks for each side of presentation within each mode, measured in terms of correctly identified dots.

Table 6

Analyses of Variance Within the Tactual-Static Mode.

Patterns

Source	SS	df	MS	F
Gender	0.64	1	0.64	0.21
Subjects(G)	24.12	8	3.01	
Learning	23.46	4	5.86	5.67**
G x L	7.26	4	1.81	1.76
Subjects(G) x L	33.08	32	1.03	
Side	0.36	1	0.36	0.27
G x S	0.04	1	0.04	0.03
Subjects(G) x S	10.60	8	1.32	
L x S	11.54	4	2.88	3.52*
G x L x S	3.26	4	0.82	1.00
Subjects(G) x L x S	26.20	32	0.82	

Dots

Source	SS	df	MS	F
Gender	0.49	1	0.49	0.06
Subjects(G)	60.32	8	7.54	
Learning	43.16	4	10.79	3.86*
G x L	16.16	4	4.04	1.44
Subjects(G) x L	89.48	32	2.80	
Side	2.89	1	2.89	1.36
G x S	0.25	1	0.25	0.12
Subjects(G) x S	16.96	8	2.12	
L x S	33.56	4	8.39	3.35*
G x L x S	2.80	4	0.70	0.28
Subjects(G) x L x S	80.04	32	2.50	

*$p<.025$
**$p<.005$

Table 7

Analyses of Variance Within the Tactual-Dynamic Mode.

Patterns

Source	SS	df	MS	F
Gender	1.96	1	1.96	0.71
Subjects(G)	22.24	8	2.78	
Learning	5.20	4	1.30	0.79
G x L	2.64	4	0.66	0.40
Subjects(G) x L	52.96	32	1.65	
Side	1.96	1	1.96	3.50
G x S	0.36	1	0.36	0.64
Subjects(G) x S	4.48	8	0.56	
L x S	3.84	4	0.96	1.03
G x L x S	3.44	4	0.86	0.92
Subjects(G) x L x S	29.92	32	0.93	

Dots

Source	SS	df	MS	F
Gender	11.56	1	11.56	1.93
Subjects(G)	47.80	8	5.97	
Learning	19.26	4	4.81	1.22
G x L	7.34	4	1.83	0.47
Subjects(G) x L	126.00	32	3.94	
Side	12.96	1	12.96	19.79**
G x S	4.00	1	4.00	6.11*
Subjects(G) x S	5.24	8	0.66	
L x S	7.34	4	1.83	0.63
G x L x S	18.70	4	4.67	1.60
Subjects(G) x L x S	93.76	32	2.93	

*$p<.05$

**$p<.005$

interaction between gender and side ($F=6.11$; d.f.=1,8; $p<.05$), the means for which are given in Table 8.

Visual. Within the visual mode (see Table 9) only the effect of side of presentation was significant for both patterns ($F=15.78$; d.f.=1,8; $p<.005$) and dots ($F=46.66$; d.f.=1,8; $p<.001$).

Shift Errors

With respect to shift errors, wherein the subject reported the dots in the appropriate relationship to each other but with the complete pattern shifted by one position horizontally or vertically (e.g., stimulus 124 reported as 235 or stimulus 456 reported as 123), the only significant effect in the analysis across all modes was that of learning ($F=3.56$; d.f.=4,96; $p<.01$). The mean number of shift errors for each of trial blocks 1 through 5 were 0.32, 0.27, 0.45, 0.13, and 0.23, respectively. The difference between mean number of shift errors per block of trials for the left (0.31) and right (0.25) sides of presentation was not significant, though in the predicted direction. Analysis of each of the three modes, individually, provided no significant effects with regard to shift errors.

Order

Tables 10 and 11 contain summaries of the overall

Table 8

Gender x Side Interaction
Within the Tactual-Dynamic Mode.

	Left	Right
Male	7.52	7.84
Female	7.80	8.92

Table 9

Analyses of Variance Within the Visual Mode.

Patterns

Source	SS	df	MS	F
Gender	0.25	1	0.25	0.03
Subjects(G)	58.56	8	7.32	
Learning	8.16	4	2.04	1.83
G x L	2.80	4	0.70	0.63
Subjects(G) x L	35.64	32	1.11	
Side	10.89	1	10.89	15.78*
G x S	0.09	1	0.09	0.13
Subjects(G) x S	5.52	8	0.69	
L x S	2.96	4	0.74	1.10
G x L x S	0.56	4	0.14	0.21
Subjects(G) x L x S	21.48	32	0.67	

Dots

Source	SS	df	MS	F
Gender	4.84	1	4.84	0.32
Subjects(G)	119.32	8	14.91	
Learning	16.26	4	4.06	1.35
G x L	18.06	4	4.51	1.50
Subjects(G) x L	96.48	32	3.01	
Side	29.16	1	29.16	46.66**
G x S	0.04	1	0.04	0.06
Subjects(G) x S	5.00	8	0.62	
L x S	8.34	4	2.08	0.81
G x L x S	4.06	4	1.01	0.39
Subjects(G) x L x S	82.40	32	2.57	

$*p<.005$
$**p<.001$

Table 10

Overall Analysis of Variance for Patterns, Including Order and Excluding Gender.

Source	SS	df	MS	F
Order	10.31	4	2.58	0.54
Mode	38.13	2	19.06	3.96*
O x M	25.31	8	3.16	0.66
Subjects(O x M)	72.15	15	4.81	
Learning	28.25	4	7.06	6.56****
O x L	34.79	16	2.17	2.02*
M x L	8.57	8	1.07	1.00
O x M x L	34.99	32	1.09	1.02
Subjects(O x M) x L	64.59	60	1.08	
Side	9.36	1	9.36	14.12***
O x S	3.09	4	0.77	1.16
M x S	3.85	2	1.92	2.90
O x M x S	8.05	8	1.01	1.52
Subjects(O x M) x S	9.95	15	0.66	
L x S	2.15	4	0.54	1.12
O x L x S	26.48	16	1.65	3.45****
M x L x S	16.19	8	2.02	4.22****
O x M x L x S	29.58	32	0.92	1.93**
Subjects(O x M) x L x S	28.78	60	0.48	

*$p<.05$
**$p<.025$
***$p<.005$
****$p<.001$

Table 11

Overall Analysis of Variance for Dots,
Including Order and Excluding Gender.

Source	SS	df	MS	F
Order	27.02	4	6.75	0.66
Mode	92.01	2	46.00	4.47*
O x M	63.06	8	7.88	0.77
Subjects(O x M)	154.25	15	10.28	
Learning	68.09	4	17.02	5.33***
O x L	75.01	16	4.69	1.47
M x L	10.59	8	1.32	0.41
O x M x L	87.00	32	2.72	0.85
Subjects(O x M) x L	191.49	60	3.19	
Side	38.16	1	38.16	31.72***
O x S	4.35	4	1.09	0.90
M x S	6.85	2	3.42	2.84
O x M x S	9.09	8	1.14	0.94
Subjects(O x M) x S	18.05	15	1.20	
L x S	9.49	4	2.37	1.16
O x L x S	61.41	16	3.84	1.88
M x L x S	39.75	8	4.97	2.43**
O x M x L x S	97.64	32	3.05	1.49
Subjects(O x M) x L x S	122.66	60	2.04	

*p<.05
**p<.025
***p<.001

analyses of the effect of order for patterns and dots, respectively. Note that the data has been collapsed over gender to allow degrees of freedom for the error terms. As with the original analysis for patterns, significance occurred for mode ($F=3.96$; d.f.=2,15; $p<.05$), learning ($F=6.56$; d.f.=4,60; $p<.001$), side ($F=14.12$; d.f.=1,15; $p<.005$), and the interaction of mode x learning x side ($F=4.22$; d.f.=8,60; $p<.001$). The main effect of order was not significant. However, order did interact significantly with learning ($F=2.02$; d.f.=16,60; $p<.05$), learning x side ($F=3.45$; d.f.=16,60; $p<.001$), and mode x learning x side ($F=1.93$; d.f.=32,60; $p<.025$). With respect to dots, order did not have any significant main effect, nor did it enter into any significant interaction. The findings of significance, in the original analysis, were replicated for the effects of mode ($F=4.47$; d.f.=2,15; $p<.05$), learning ($F=5.33$; d.f.=4,60; $p<.001$), and side ($F=31.72$; d.f.=1,15; $p<.001$). In addition, the mode x learning x side interaction, which was not significant in the original analysis for dots, was found to be significant in this analysis ($F=2.43$; d.f.=8,60; $p<.025$).

In terms of shift errors, order did not have a significant main effect. As with the original analysis of shift errors, only learning was significant ($F=5.07$; d.f.=4,60; $p<.005$). Order did interact significantly with learning ($F=2.14$; d.f.=16,60; $p<.025$) and learning x side

($F=2.98$, d.f.$=16,60$; $p<.005$).

Discussion

The present study has shown that at least some of the functional differences between the two hemispheres in normal adult humans, as determined chiefly through experiments in the visual mode, exist as well in the perception of tactile stimuli. Though the similarity is not completely unqualified, it is sufficiently substantial to provide further clarification of the analytical procedures used by the two major halves of the human brain. Thus, this study also makes a contribution to the redefinition of functional lateralization.

In general, the main finding of this study was that when the two hemispheres of the human brain are required to perceive small numbers of point stimuli, presented visually or tactually, and to respond by numerical identification of each of those stimuli, the left hemisphere is superior to the right. This is true whether performance is measured in terms of identification of individual stimuli or of complete groups of stimuli, though not so emphatically in the latter case. This contradicts the expectation one would have if he were to consider the stimuli only in terms of their verbal versus spatial properties. Such an expectation would be that the right hemisphere would be superior in determining the positional or spatial aspects of such stimuli as used in this study (Hermelin and O'Connor, 1971; Kimura, 1969; McKeever and Hulling, 1970; Rudel Denckla, and Spalten,

1974). As a result, it seems necessary to reconsider our position with regard to the basis of hemispheric laterality. What will be suggested and discussed in the following pages is that hemispheric differences stem from differences in the manner of processing incoming information. It will be seen that the left hemisphere is specialized for processing items, or elements, of information, while the right hemisphere's specialty is the processing of configurations of items.

Since no significant differences were found within the practice trials, it was concluded that the subjects participating in this study were from a fairly homogeneous population and that any predisposing tendencies were spread evenly throughout the three presentation-mode groups. It was also concluded that the relative abilities of the two sides (hemispheres) could not be distinguished at such a low level of stimulus complexity. Lastly, since neither gender exhibited a greater ability than the other at this task, it was concluded that any differences occuring on the more difficult experimental tasks would be interpretable in terms of both task difficulty and different hemispheric usage by the two genders.

According to the analyses of both patterns and dots, the subjects perceiving the dot stimuli via the TD mode did significantly less well at reporting the dot positions than did those in the other two groups, specifically those in the

TS group. This was not consistent with the expected results. The prediction at the outset of the study, based on previous research (Apkarian-Stielau and Loomis, 1975; Loomis, 1974), was that dynamic presentation of the patterns would facilitate perception of them. A very likely interpretation of the discrepancy is that scanning of a stimulus array will only facilitate its perception when the array is at or above a certain level of complexity, and only when scanning significantly reduces the complexity of the array while maintaining sufficient information content. Upon re-examination of the two articles by Loomis and Apkarian-Stielau, one finds this interpretation substantiated by the different degrees of effectiveness of slit-scanning between two groups of letters. Perception of each of the letters of the first group (A,H,I,J,L,M,N,T,U,V,W,Y) was facilitated by scanning because the process essentially produces a sequential tracing of each letter. The complexity of each of the letters in the second group (B,C,D,E,F,G,K,O,P,Q,R,S,X,Z) did not allow this to occur.

The stimulus patterns used in the present study are not very complex, and it seems that scanning, in this case, serves only to disorient the subject by disrupting his frame of reference, i.e., the stimuli do not remain at the same points on his fingertip as they do in the TS mode. The subject may rely only upon interstimulus distances for positional information. Thus, scanning, in this case,

reduces the information content without the necessary concomitant reduction of complexity.

As the TS and V modes were not significantly different, in terms of the subjects' overall performance, it would appear that the manner of presentation of the visual stimuli has made their perception about as difficult as that of the tactile stimuli. From this, in conjunction with the other similarities between visual and tactual presentation in this study, it would appear that a number of intermodality comparisons may be made.

It is also evident that learning occurred in both the patterns and dots measures across the three modes. This was expected due to the lack of experience of the subjects with this type of stimuli. However, even blind people experienced with Braille show some learning occurs when using the relatively "naive" middle finger to perceive the stimuli (Hermelin and O'Connor, 1971).

The side of presentation, with which the present study is especially concerned, reliably affected response accuracy and was most apparent when the data from the three modes were combined. However, it was in the <u>opposite</u> direction from the one predicted! Based on previous research, one would have predicted that the "spatially organized" right hemisphere should be more able to perceive the patterns of dot stimuli and should thereby have less difficulty in

determining the positions of the individual dots. That the left hemisphere was superior suggests that its ability to construct the pattern through accurate perception of the positions of the individual dots was given the advantage by the task requirements imposed by this experiment. This point will be elaborated upon later.

The interaction between mode, learning, and side of presentation, which was significant in the overall analysis based on patterns, is described clearly in Figure 1. Briefly, it appears that while the relative increases in performance for the two sides are somewhat consistent between the TD and V modes, in the TS mode something quite different has occurred. The accuracy of reporting stimuli presented to the left hand is much higher on the last two blocks of trials than on the first three, while no substantial increase is evident for the right hand stimuli. It would seem that considerably more learning has occurred with the left side than with the right (as confirmed by the analysis for difference in trends). In fact, there is a dramatic reversal of superiority in the TS mode. This reversal suggests that the right hemisphere, though originally somewhat handicapped in its attempt to deal with the groups of dot stimuli as patterns, was eventually able to capitalize upon the consistency of the complete array and radically increase its performance. Of the three modes of presentation, only the TS mode provided support for the

prediction that the right hemisphere would show an increase in performance while the left hemisphere's performance remained relatively constant.

The probable reason for lack of confirmation in the TD mode is that the right hemisphere was unable to overcome the disorientation produced by the scanning. In the V mode also, the right hemisphere seems to have been prevented from increasing its performance to any great extent. This was probably also due to the difficulty of perceiving the full patterns as easily as perceiving only one or two dots in each. This will be further clarified in the discussion of the different processing strategies of the two hemispheres.

Consideration of only the two tactual modes shows that the effects of mode and learning were further substantiated with respect to both patterns and dots. However, in the analysis of the pattern data, the effect of side of presentation seems to have been eliminated by the mode x learning x side interaction. In the analysis based on dots, meanwhile, the effect of side was sufficiently strong to prevent the interaction from reaching significance. This is indicative of the difference between the relative abilities of the two hemispheres in this type of task. As mentioned previously, while the right hemisphere initially concerns itself with the whole patterns, the left is concerned primarily with the specific elements of the patterns. Thus, the superiority of the left hemisphere is more apparent in

the analysis based on dots than in that based on whole patterns.

The TS mode, taken individually, was the only one of the three in which a significant laterality effect did not occur in either the patterns or dots analysis. It appears, in Figure 1 (top), that if the trend set by the first three trial blocks was to continue, a significant laterality effect would, in fact, have have been found. However, as a result of the large increase in the performance of the right hemisphere, which produced the significant learning x side interaction, as well as a significant overall learning effect within TS, the effect of side of presentation was obscured.

In the TD mode it was found that the analysis based on patterns provided no significant effects. Though there appears to have been an upward tendency across trial blocks (see Table 5), it was not consistent enough or of sufficient magnitude to be significant. This was probably due to the difficulty of the task. Significant learning possibly would have occurred had there been more trials. As far as side of presentation is concerned, the most probable explanation for a lack of significant difference is, again, that the superiority of the left hemisphere is reduced when performance on whole patterns is considered. As stated above, this aspect of the task is more closely related to the abilities of the right hemisphere than is that of

reporting single dot positions.

When performance in reporting individual dot positions in the TD mode was considered, the effect of side of presentation was significant. Thus, in the most difficult of the three presentation modes, based on the subjects' overall performance, we find the distinct superiority of the left hemisphere. The contrast between the results of the two tactual modes may be explicated through further reference to their relative degrees of difficulty. It would seem that, in the TS mode, the right hemisphere, though it had begun at a relatively low level of performance, was able to take advantage of the consistency of the array and improve its performance over trials. In the TD mode it was unable to do so. Referring back to the discussion of the probable effects of scanning in this situation, one may suggest that the latter reduced the amount of information about the total array and thus reduced the ability of the right hemisphere to increase its performance. Note that there is not a significant learning effect in the dots (as well as patterns) analysis in the TD mode. This does pose the question of to what extent further experience with the task would facilitate an increase in the performance of one or both hemispheres.

In the V mode the effect of side of presentation was reliable in the analyses of both patterns and dots. That performance was consistently better when the stimuli were

presented to the right visual field contradicts the prediction made at the outset of the experiment. However, it does not negate the useability of the visual data as a basis for comparison of the tactual data. It is necessary merely to understand that the prediction was founded upon assumptions which were either incorrect or incomplete, more than likely the latter.

It is somewhat curious that the expected effect of gender occurred only in the TD mode. Originally, based upon the assumption that the right hemisphere would prove superior on this task, and on the findings of Kimura (1969), and others, it was predicted that males would do better than females, or at least show a greater right hemisphere superiority than the latter. Since the main effect of side of presentation was opposite to that predicted, one would then expect females to do better, or show a greater left hemisphere superiority (Rudel, Denckla, and Spalten, 1974; McGlone and Davidson, 1973; McGlone and Kertesz, 1973). The significant interaction between gender and side of presentation in the TD mode supports this contention. It appears that the tendency for females to perform better with the left hemisphere than with the right has combined with the requirements of the present task to produce a large discrepancy between the two sides. With males, however, the tendency to perform better with the right hemisphere has decreased the effect of the task requirements used in this

study, though it does not reverse it. Difficulty in assessing the significance of a gender effect is clearly indicated by Fairweather (1976), who more than adequately points out that sex differences and their interpretations are quite questionable in most studies, and the present study is no exception.

The analysis based on shift errors provided little useful information. However, there was an indication that the right hemisphere was more prone to commit such an error. This is consistent with the predictions made at the outset of the experiment, specifically with regard to the tendency of the right hemisphere to be more concerned with the array as a unit than with the specific positions of its isolated parts. The left hemisphere, however, should not make as many of these errors for the opposite reason. Perhaps, with a different task situation, such as recognition, this effect would have proved statistically significant.

The finding of a statistically significant difference among the blocks of trials, with regard to shift errors, is not the result of any systematic trend. Most likely, it is due to a chance preponderance of the stimuli on which these errors can occur within the same one or two trial blocks within more than one order.

In the analyses aimed at detecting order effects, it was found that different orders had different influences on

the rate of learning, at least with respect to patterns. This might be expected, since not all the stimulus patterns were of the same difficulty and the more difficult ones were likely to be presented in varying places among the different orders. The fact that order entered into no significant interaction, when performance was measured in terms of individual dots, substantiates this explanation.

Processing Stategies

It now remains to discuss the most probable explanation for the apparent disagreement between the results of the present study and those of most previous studies.

The matter of verbal naming of stimuli or bits of information is important here. The ability to label items of information would seem to be more or less specifically within the realm of the left hemisphere (Bryden, 1970; Hillyard, 1973; Kimura, 1966). This would lead one to suggest that whenever some form of labelling activity is required, the left hemisphere would carry out the task. However, Hermelin and O'Connor (1971) have shown that this is not necessarily the case, at least with regard to tactually perceived information. Recall that, in their experiment, persons experienced with Braille patterns were better at naming and combining such patterns when the latter were perceived via the left hand. In the present experiment, when subjects, who were not experienced with Braille, were

asked to name the individual dot positions within each pattern, they performed better when the patterns were presented to their right hands or visual fields. Nevertheless, the right side superiority on the tactually presented patterns was not as great as on the visually presented patterns. In fact, in one tactual group (TS) the left side performance overtook and was definitely better than the right side performance in the last two trial blocks. This, in conjunction with the findings of Hermelin and O'Connor, suggests that two events have occurred in the present study, one in which the general processing strategy of the human brain is expressed, and the other in which that processing applies specifically to tactually perceived information.

It seems that the primary question one must ask in determining the relative abilities of the two hemispheres is to what extent a perceived stimulus must be processed before it may be identified. If a stimulus is limited in information content, or is easily identifiable from a small number of its parts, it will necessarily be handled more efficiently by a feature-analytic method than by a wholistic method. On the other hand, the latter would be better at the processing of more complex or not so easily identified stimuli. At the outset of this experiment, numerical identification of the dot stimuli was not expected to bias the results to any great extent, in accordance with the

findings of Hermelin and O'Connor (1971). However, this assumption was somewhat crucial to the outcome of the experiment.

A distinction may be made between the task requirements of this experiment and those of Hermelin and O'Connor. In their study, the subjects were required to perceive the complete pattern of stimuli <u>before</u> any additional analysis or interpretation could be made. The present study, however, required that the subject identify each individual stimulus position. It was thought that the presentation of stimuli in groups, or patterns, would facilitate identification and thus lead to a right hemisphere superiority. If, in fact, such patterning does not produce sufficient facilitation, right hemisphere superiority should not occur. The left hemisphere, then, seems to be able to count, or itemize, the incoming information when the latter is somewhat limited in content. The right hemisphere, on the other hand, appears to handle rather large amounts of information as units or groupings, without much attention to the individual elements contained therein.

Essentially, it seems that the dichotomy between the two hemispheres is not merely one of verbal versus non-verbal, but a more basic one of feature-analytic perception versus "Gestaltic" perception. It would seem that, in order for the "spatial" (right) hemisphere to be more proficient at this task, each dot pattern must be dealt with as a

whole. If the stimulus is more easily perceived as three separate units (dots), the left hemisphere would be expected to be the more able (Semmes, 1968; Levy, Trevarthen, and Sperry, 1972). Seamon and Gazzaniga (1973) have shown that task requirements, in terms of instructions requiring either verbal rehearsal or visual-imaginational memory, can specifically direct processing of information to one hemisphere or the other, regardless of the form (verbal or pictoral) of the information. Bartholomeus (1974) has found similar effects in the auditory mode. This agrees with the contrast between the present work and those of Hermelin and O'Connor (1971) and Rudel, Denkla, and Spalten (1974). It follows that if the response mode, or any other aspect of the task, compels the subject to attend more to each dot as an individual than to the complete pattern, the abilities of the right hemisphere might be superceded by those of the left.

Thus, we come to the general conclusion that the left hemisphere is nct merely "verbal" but "feature-analytic", while the right hemisphere is not merely "spatial" but "Gestaltic", or "holistic". Some authors prefer to make this differentiation in terms of simultaneous (parallel) versus successive (serial) processing (Cohen, 1973; Das, Kirby, and Jarman, 1975; Papcun, et al., 1974), but it seems somewhat difficult to distinguish this from holistic/feature-analytic terminology.

It would seem that the intrinsic neurological/anatomical structure of the visual, auditory, and somesthetic senses would differentially influence the mode of processing. Thus, the complexity of the stimulus, together with its familiarity to the perceiver and the requirements of the task situation, should interact with the input modality to determine which mode of processing will be superior. (Whether or not both processing modes are always active is another question.) For example, one would assume that the auditory mode, primarily a temporal processor, deals with input in a sequential manner. However, music is generally processed by the right hemisphere (Kimura, 1964). Yet, Bever and Chiarello (1974) have shown that practiced musicians deal with music mainly with their left hemisphere. In addition, Papcun, et al. (1974) have shown that naive subjects show left hemisphere superiority when given dichotically presented Morse code letter pairs containing up to seven elements (dots and/or dashes), as do experienced Morse code operators. However, when the number of elements in the letter pairs was increased beyond seven, the naive subjects showed a reversal of superiority (to the right hemisphere), though the experienced ones did not. Other authors dealing with audition (Bakker, 1967; Robinson and Solomon, 1974) have provided further supporting evidence on this account. Likewise, while tactile perception would generally appear to be holistic or simultaneous, Lechelt and

Tanne (1976) have shown that the left hemisphere is the main processor in some instances. Presenting from five to thirteen mechanical pulses to the middle fingertips, via a .63-cm diameter contactor, they found that trains of up to seven pulses were more accurately counted when delivered to the preferred hand (right hand in dextrals). However, trains of more than seven pulses were more accurately counted when presented to the nonpreferred hand. Note the recurrence of Miller's (1956) limitation as the point of shift in superiority. Also, in the present study the left hemisphere was superior, at least until the right hemisphere gained enough experience to supercede it (in the TS mode).

The present results seem to have implications beyond merely describing the type of material generally dealt with by the hemispheres to the actual strategies by which each processes all material. This approach to the topic is not entirely new (Levy, 1969), but most authors still tend to disregard it in their discussion. However, it has recently become more acceptable as a framework within which the large amount of information in this area may be organized (Bever, 1975).

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Appendix I

Handedness Inventory

A. Are you righthanded or lefthanded?
Right Left Mixed

B. Do you consider yourself to be strongly, moderately, or weakly righthanded or lefthanded?
Strong Moderate Weak

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1. With which hand do you write? Right Left Mixed
2. With which hand do you use a tennis racquet? Right Left Mixed
3. With which hand do you use a screwdriver? Right Left Mixed
4. With which hand do you throw a ball? Right Left Mixed
5. With which hand do you use a needle in sewing? Right Left Mixed
6. With which hand do you use a hammer? Right Left Mixed
7 With which hand do you light a match? Right Left Mixed
8. With which hand do you use a toothbrush? Right Left Mixed
9. With which hand do you deal cards? Right Left Mixed
10. With which hand do you hold a knife when carving meat? Right Left Mixed

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1. Is your father righthanded or lefthanded? Right Left Mixed Don't Know
2. Is your mother righthanded or lefthanded? Right Left Mixed Don't Know

3. If you have any siblings (brothers or sisters), give the sex, age, and handedness of each (write in more blanks if needed).

   1) Sex___Age___Handedness: Right Left Mixed Don't Know
   2) Sex___Age___Handedness: Right Left Mixed Don't Know
   3) Sex___Age___Handedness: Right Left Mixed Don't Know
   4) Sex___Age___Handedness: Right Left Mixed Don't Know
   5) Sex___Age___Handedness: Right Left Mixed Don't Know

From Varney, N.R. and Benton, A.L. (1975).

Appendix IIA

Tactual Instructions

This experiment is concerned with the sense of touch, or somesthesis. We are attempting, here, to evaluate some aspects of the ability of humans to perceive tactile stimuli. I cannot fully explain the intent of the experiment at this time, but I will be quite willing to give a full explanation, and answer any questions you may have, after the experiment is completed. I will now inform you as to what we would like you to do during the experiment.

First, I would like you to place your hands on this platform, like this, so that your middle fingers fit snugly into these guides and rest in the holes at the end of the guides. They should be comfortable, as they are to remain there for most of the experiment . ...

Now, what I am going to do is to place a small pattern of six dots under each finger. The six dots are arranged like this . ... Are you able to feel the full array on both sides? You will notice that the stimuli are able to move up and down. Please put equal pressure on both sides so that they remain level.

Now, consider the numbers on this card. Each dot has been given a number from 1 to 6. Please memorize the positions of the numbers.

Now we are going to have a number of trials during which a single dot will be presented on one side or the other. Each trial will be the same, except that the position and side of the dot will vary. First, this light will go on for a short time, followed shortly by the removal of the barrier between your fingers and the stimulus. When the barrier is removed please lower the tips of your fingers onto the stimulus as quickly as possible. Press down with both fingers, even though the stimulus is only on one side, since, if you don't press down with one finger, you won't be able to feel the other side very well.

You will have very little time to feel the stimulus, but please do not attempt to move your finger in the guide as this will reduce your ability to accurately tell where the dot is. As soon as the stimulus has dropped away from your finger please say the number of the position that it was in. Immediately after you have given your response I will tell you whether or not it is correct and, if not, what the correct response is. In this way, you will eventually learn where the dots are under your fingertips . ...

Now we are going to begin a series of slightly

different trials. From now on, each stimulus will consist of three dots.

For TD: Also, from now on, this platform will move from side to side over the stimulus during each trial. Please allow your fingertips to follow with the movement of the platform.

Immediately after the stimulus pattern has dropped away from your fingertips please give the three numbers designating the three dot positions in the stimulus. I will not give you any feedback during these trials since I will not know whether or not your responses are correct.

Appendix IIB

Visual Instructions

This experiment is concerned with the sense of vision. We are attempting, here, to evaluate some aspects of the ability of humans to perceive visual stimuli. I cannot fully explain the intent of the experiment at this time, but I will be quite willing to give a full explanation, and answer any questions you may have, after the experiment is completed. I will now inform you as to what we would like you to do during the experiment.

First, I would like you to look into this apparatus so that your face fits snugly into this guide and you can see directly through the slots. You should be comfortable, as you are to remain in that position for most of the experiment. ...

Now, what I am going to do is to place two small patterns of six dots each in front of your eyes. The six dots are arranged like this. You will notice first a small "plus" mark in the center of the screen. Please look directly at that mark. ... Were you able to see the full array on both sides?

Now, consider the numbers on this card. Each dot has been given a number from 1 to 6. Please memorize the positions of the numbers.

Now we are going to have a number of trials during which a single dot will be presented on one side or the other. Each trial will be the same, except that the position and side of the dot will vary. First, the small "plus" symbol will appear for a short time, followed immediately by the dot. When the + symbol is shown please look directly at it. Do not look to one side of the +, as this will reduce your chances of seeing the dot properly if it is presented on the other side.

The dot will be presented for a very brief period. As soon as it has been presented please say the number of the position that it was in. Immediately after you have given your response I will tell you whether or not it is correct and, if not, what the correct response is. In this way, you will eventually learn where the dots are on the screen. ...

Now we are going to begin a series of slightly different trials. From now on, each stimulus will consist of three dots.

Immediately after the stimulus pattern has been presented please give the three numbers designating the

three dot positions in the stimulus. I will not give you any feedback during these trials since I will not know whether or not your responses are correct.

Appendix III

Stimulus Orders

Five random orders of twenty stimuli, presented twice, once to each side. Each order is divided into five blocks of eight stimuli, each block containing four presentations to each side.

Order 1.

	1	2	3	4	5
1	R20	R10	L9	L13	R13
2	L17	L16	R1	L8	L10
3	L19	R18	R16	R5	L3
4	R6	L11	L14	L15	R15
5	L7	L2	R17	R9	L4
6	L1	R19	L20	L18	R8
7	R12	R14	L12	R2	L6
8	R4	L5	R3	R7	R11

Order 2.

	1	2	3	4	5
1	R17	L8	L20	L2	R5
2	L12	L1	R8	R13	R2
3	R15	R6	L11	R18	L17
4	R3	R20	L14	L5	R16
5	L4	L16	R10	R14	L6
6	R9	R4	L13	L15	L3
7	L7	L19	R19	R11	R1
8	L10	R7	R12	L18	L9

Order 3.

	1	2	3	4	5
1	L17	L11	R8	L10	R2
2	R1	R5	L20	R18	L13
3	R4	R20	R14	L15	R19
4	L19	L4	R3	R16	L6
5	L3	R17	L2	R13	R10
6	R11	R15	L18	L8	L7
7	L1	L5	R12	R7	L12
8	R9	L9	L14	L16	R6

Order 4.

	1	2	3	4	5
1	R16	R6	R1	L8	L1
2	R13	R18	L3	L6	R12
3	L12	L2	R4	R20	L19
4	R17	L17	L5	L9	R14
5	L20	R5	L11	R3	L7
6	R7	L13	R9	R15	R8
7	L18	L15	L16	L4	R2
8	L10	R10	R19	R11	L14

Order 5.

	1	2	3	4	5
1	L8	L17	R14	R18	R4
2	L15	R15	L5	L10	L19
3	R20	L12	R10	L1	L13
4	R5	R16	L6	R11	R3
5	L3	R19	R13	R12	L9
6	R6	L7	R7	L18	R2
7	R8	L2	L14	R1	R17
8	L16	R9	L11	L20	L4